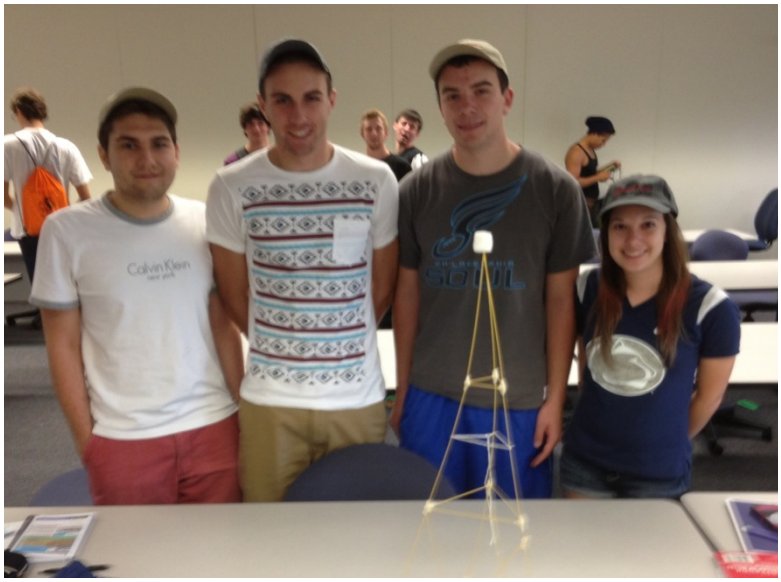
# 2013

# Zero Energy Home Project



EDSGN 100 Section 009

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# Executive Summary

Our Team has been assigned the task of designing a Zero Energy Home, or ZEH. This semester we are all taking Engineering Design 100 because of our Pre-Engineering status. As engineers we are tasked with solving the worlds problems and today there is a need for more efficient uses of the dwindling resources around us. Homes are structures that, on average, are inefficient and consume large amounts of energy while producing an equally large amount of waste. Our goal in this assignment is to design and build a house that can produce its own energy by using sustainable resources. The home must have a net energy usage less than 0, meaning it must put power back into the grid or use a net energy of zero. The home will be a modern style that will appeal to the majority of homeowners. Wind and Solar will be the main resources used in the design. Solar cells, windmills, or thermal masses will harness both energy sources. As far as smaller more technical details are concerned there will be 1 floor, 1080 sq. ft., two bedrooms and two bathrooms while all costing under $200,000.

In developing a design we sent out a survey that was replied to by 17 people. Using the data they produced we developed rough specifications of our ZEH. The detail that was agreed upon the most was the desire for solar panels and a windmill. Opinions like these shaped the basis for our concept. The six customer needs that appeared the most important important were type of energy, number of floors, square footage, number of bathrooms, house material, and appliances. We were tasked to make a house that is appealing to the customer and at the same time is capable of supporting a family of four. We will also complete a scale model of the house and a Solid Works model. We found different ways to meet these needs and ranked the possibilities using a scoring matrix.

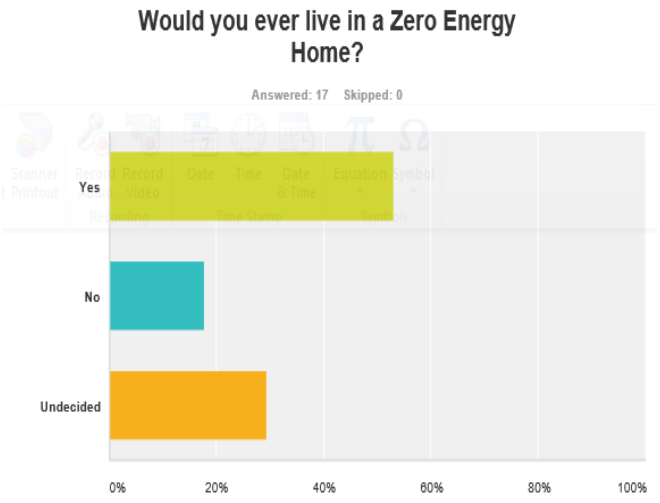
Technical risks include failure of key structural components in the house. For example, major weight bearing supports could fail if not properly supported causing a collapse and possible loss of life. Additionally, as with any home, utilities like electric and plumbing must be properly installed and maintained to prevent failure resulting in flooding or electrical fires. The programmatic risks include meeting deadlines and the $200,000 budget. Technical risks can be avoided by using proper building codes and strong, reliable material. To prevent failure to meet major deadlines we use the project plan with short term deadlines. The budget will be maintained by using low cost materials and clear budgeting techniques.

# Introduction

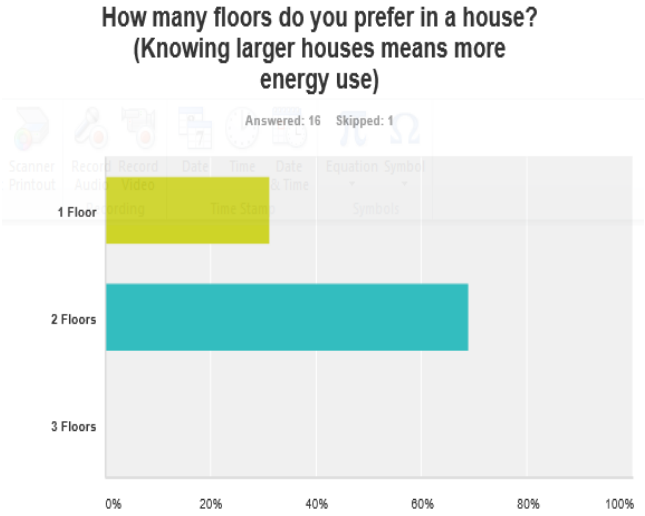
Our team was delivered with the task of building a Zero Energy Home that not only fit the needs of a family of four, but also stayed under a project budget of $200,000. Zero Energy Homes are becoming a necessity in today's society, since we are losing many of our natural resources. Zero Energy Homes are able to help us maintain these resources, and help reduce pollution to our environment at the same time. After many hours of research and brainstorming, we were able to design a house that met all of these specifications.

# Customer Needs Analysis

Our customer needs came from a survey that we created together and then put online. Friends and family of ours helped fill out the survey for us. From their responses, we were able to collect a lot of useful data for our home. We found that more than 50% would live in a zero energy home if they could. Although a lot more of the responders said they would like a two story home, we went with a one story home to help keep it the most energy efficient it could be. They also said they would like the home to be roughly 1500-2000 square feet, which we were able to incorporate into our house. Almost half said they would pay $200,000 for the home, which was exactly what our budget ended up becoming. About 70% voted for solar power being the main source of renewable energy, and to have the solar panels put on the roof. The voters also wanted a wooden rectangular house with at least two bathrooms if possible. Also, they did not find windmills unattractive on their property, which helped us increase our energy output in the end. You can see all of the data that was collected on the next few pages.



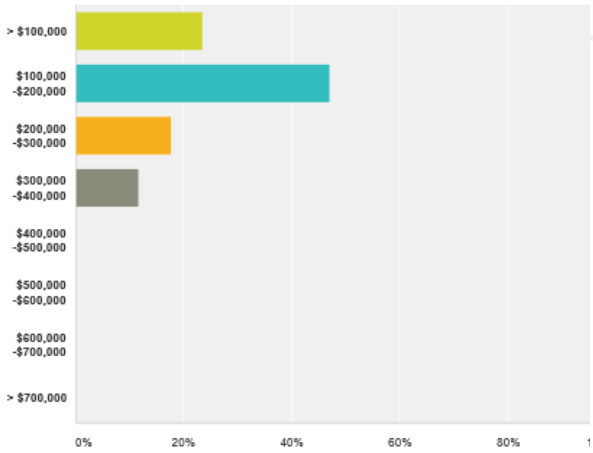

| Answer Choices | Responses | |
|---|---|---|
| Yes | 52.94% | 9 |
| No | 17.65% | 3 |
| Undecided | 29.41% | 5 |
| Total | | 17 |




| Answer Choices | Responses | |
|---|---|---|
| 1 Floor | 31.25% | 5 |
| 2 Floors | 68.75% | 11 |
| 3 Floors | 0% | 0 |
| Total | | 16 |

## How much would you be willing to pay Zero Energy Home?

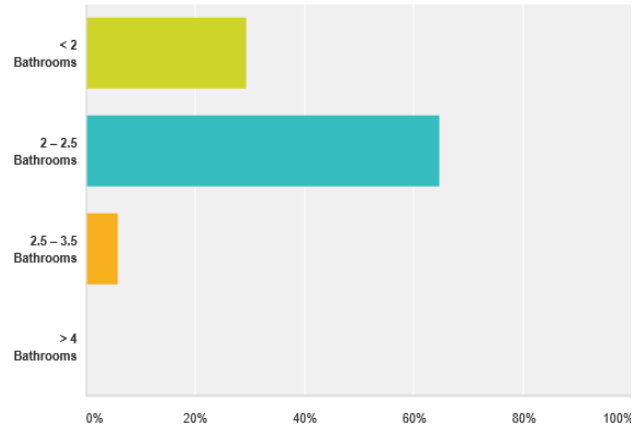
Answered: 17 Skipped: 0




| Answer Choices | Responses |
|---|---|
| > $100,000 | 23.53% |
| $100,000 -$200,000 | 47.06% |
| $200,000 -$300,000 | 17.65% |
| $300,000 -$400,000 | 11.76% |
| $400,000 -$500,000 | 0% |
| $500,000 -$600,000 | 0% |
| $600,000 -$700,000 | 0% |
| > $700,000 | 0% |
| Total | 17 |

## How many bathrooms would you like?

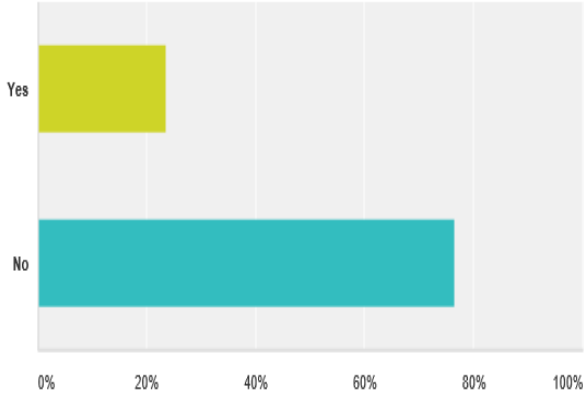
Answered: 17 Skipped: 0




| Answer Choices | Responses | |
|---|---|---|
| < 2 Bathrooms | 29.41% | 5 |
| 2 – 2.5 Bathrooms | 64.71% | 11 |
| 2.5 – 3.5 Bathrooms | 5.88% | 1 |
| > 4 Bathrooms | 0% | 0 |
| Total | | 17 |

## Do you find windmills unattractive if they were on your property?

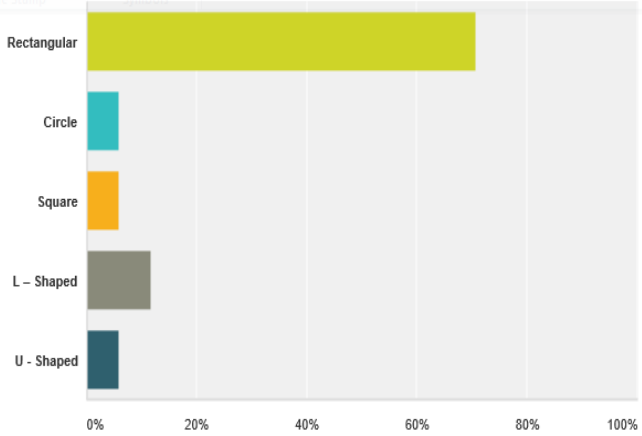
Answered: 17 Skipped: 0



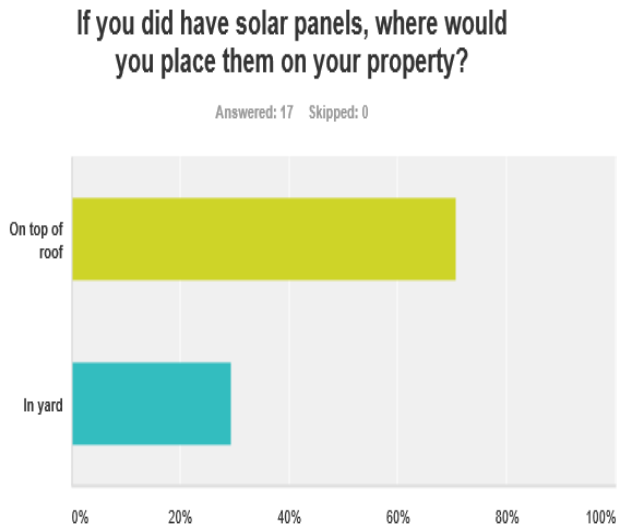

| Answer Choices | Responses | |
|---|---|---|
| Yes | 23.53% | 4 |
| No | 76.47% | 13 |
| Total | | 17 |

## What shape would you prefer your house?

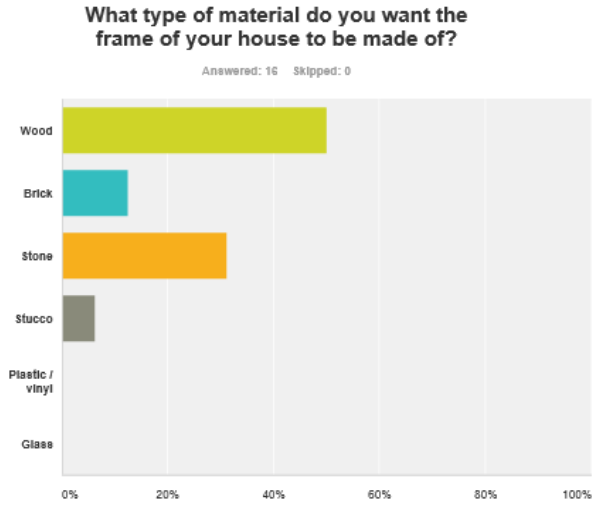
Answered: 17 Skipped: 0




| Answer Choices | Responses | |
|---|---|---|
| Rectangular | 70.59% | 12 |
| Circle | 5.88% | 1 |
| Square | 5.88% | 1 |
| L – Shaped | 11.76% | 2 |
| U - Shaped | 5.88% | 1 |
| Total | | 17 |




| Answer Choices | Responses | |
|---|---|---|
| On top of roof | 70.59% | 12 |
| In yard | 29.41% | 5 |
| Total | | 17 |




| Answer Choices | Responses | |
|---|---|---|
| Wood | 50% | 8 |
| Brick | 12.50% | 2 |
| Stone | 31.25% | 5 |
| Stucco | 6.25% | 1 |
| Plastic / vinyl | 0% | 0 |
| Glass | 0% | 0 |
| Total | | 16 |

## External Research

Renewable Energy Sources:

Hydropower

1. The use of water to generate electricity
    a. Most common renewable source in the United States
2. Power plants use a dam on a river to store water
3. Water is released from behind the dam and then flows through a turbine
    a. Turbine spins which generates electricity
        i. Hydroelectricity
        ii. 7% of the electricity used by the nation
4. Least expensive sources of electricity

Wind Power

1. The use of wind to generate electricity
2. Usually have two or three blades and are mounted on tall towers to capture the most energy
    a. Blades turn which causes the central shaft to spin a generator to create electricity
3. World's fastest growing energy technology
    a. Can generate electricity without producing pollutants
    b. Supplies 1% of United States electricity needs

Solar Power

1. Use the sun's energy to provide heat, light, hot water, electricity, and even cooling for homes, business, and industry
2. Provides less than 1% of U.S. energy needs
    a. Expected to increase with the development of new and more efficient solar technologies
3. Passive solar captures the sun's heat to provide space heating and light
    a. Photovoltaic cells convert sunlight into electricity
    b. Flat plate collectors absorb the sun's heat directly into water to provide hot water or space heating
4. Cost is a great drawback
    a. Electricity generated by solar cells is more than twice the cost of fossil fuels
        i. Due to only being able to operate in daylight

Geothermal Power

1. Uses the natural sources of heat inside the Earth to produce heat or electricity
    a. Generated from steam or hot water from underground
    b. Produces few emissions and the power source is continuously available
2. Three geothermal technologies
    a. Direct-use systems
        i. Used for heating buildings, raising plants in greenhouses, drying crops, heating water for fish farms, and for industrial processes
    b. Use of deep reservoirs to generate electricity
        i. Power plants use steam to drive a turbine to produce electricity
    c. Geothermal hot pumps
        i. Used for space heating and cooling as well as water heating
        ii. Transfers heat stored in the ground into a building during the winter
        iii. Meets less than 1% of U.S. power needs

Biomass Power

1. Power obtained from the energy in plants and plant derived materials
2. Provides two valuable services
    a. 2nd most important source of renewable energy in the U.S.
    b. Important part of our waste management infrastructure
3. Wood
    a. Largest biomass energy resource
4. Waste
    a. 2nd largest biomass energy resource
    b. Municipal solid waste, manufacturing waste, landfill gas
5. Used for direct heating, for generating electricity, or can be converted directly into liquid fules to meet transportation energy needs
    a. Biopower
    b. Biofuels
        i. Ethanol and biodiesel
6. Produced from plant sources so it can be potentially produced almost anywhere
7. Can reduce emissions and pollutants but can impact wildlife

How Zero Energy Homes Work:

1. As efficient as a house can get without giving up electricity
    a. Comforts of a regular house
        i. Heats, cools, entertains, washes, and dries
        ii. Does it all more efficiently
    b. Generates enough solar electricity to cover its low-energy needs
2. Construction
    a. Incorporates
        i. Solar-photovoltaic system for generating electricity
        ii. Passive solar thermal system to heat water
    b. Minimizes
        i. Space heating, cooling, and ventilation
        ii. Water heating
        iii. Lighting and appliances
3. Production
    a. Requires 60% less energy than a standard home
        i. Needs to be clean energy
    b. ZEH that needs a certain amount of kWh per square foot has PV panels that will generate that same amount kWh on average
        i. On average because of weather conditions and more energy use needed
    c. Takes from electrical grid when needed and when there is an overabundance of energy it is put back into the grid
        i. Clean energy is supplied when needed
4. Economics
    a. ZEH built in Frisco, Texas was listed at $1 million
    b. ZEH constructed in Edmond, Oklahoma had a estimated retail cost of $200,000
    c. Costs more to build than a traditional home
        i. 20-60%
    d. Regular single-family home in the U.S. pays about $2,200 a year on power
        i. Reducing this to nothing can save a family $22,000 over ten years
    e. Energy-efficiency comes down to the people maintaining it

Benchmarking:

| | |
|---|---|
| Location (city, state) | Seattle, WA |
| House size (floor area in square feet) | 1915 sqf |
| Number of floors | 2 |
| URL of web site where info is found | http://www.greenbuildingadvisor.com/homes/net-zero-energy-house-125-square-foot |
| Number of occupants | 2 |
| Number of bedrooms | 3 |
| Type of heating system (forced air, hydronic, radiant floor, heat pump, etc. | Unico UniChiller air-to-water heat pump, 3-ton, 35,400 BTU/h capacity, 9.2 HSPF. Space heat distribution: hydronic PEX tubing in first-floor slab. Hydronic heating system is supplemented by electric-resistance in-floor heating mats in upstairs bathroom. |
| Main heating fuel (electricity, natural gas, wood, oil, etc.) | Electricity |
| Size of photovoltaic system (kilowatts) | 6.4 |
| Solar water heater (yes or no) | no |
| R-value of wall insulation | 26 |
| R-value of ceiling insulation | 42 |
| Ventilation air heat recovery (yes or no) | no |
| Predicted or measured annual energy use | 1,429 kWh (12months) |

| | |
|---|---|
| Location (city, state) | Perkiomenville, PA |
| House size (floor area in square feet) | 2020 sqf |
| Number of floors | 2 |
| URL of web site where info is found | http://www.sustainabledesign.info/hpb/overview.cfm?ProjectID=722<br>http://philadelphiasustainabilityawards.org/nominees/oneil |
| Number of occupants | 2 |
| Number of bedrooms | |
| Type of heating system (forced air, hydronic, radiant floor, heat pump, etc. | Geothermal heating system and radiant floor heat<br>Tank less on-demand water heating |
| Main heating fuel (electricity, natural gas, wood, oil, etc.) | Electricity |
| Size of photovoltaic system (kilowatts) | 5.25 |
| Solar water heater (yes or no) | no |
| R-value of wall insulation | 23 |
| R-value of ceiling insulation | 45 |
| Ventilation air heat recovery (yes or no) | yes |
| Predicted or measured annual energy use | 2.845 kWh |

# Concept Generation and Selection

From our data obtained from our surveys, we then narrowed down the top choices of the questions asked. When then took this criteria and made matrices to compare the different concepts against each other. In some cases, we had to go with the concept not ranked that high, because it would help with the energy efficiency of our house. Shown below is the final process we went through to help build our Zero Energy Home.

| Selection Criteria | A Active Solar | B Passive Solar | C Wind | A Geothermal |
|---|---|---|---|---|
| Learn Engineer Design Process | + | + | + | + |
| Scale Model | 0 | + | 0 | - |
| 3-D Computer Model | 0 | 0 | 0 | - |
| Meets Needs of Family of Four | + | + | - | 0 |
| Aesthetically Pleasing/ Atrractive Appearence | - | + | + | 0 |
| Sustainability | + | + | + | + |
| Sum +'s | 3 | 5 | 3 | 2 |
| Sum 0's | 2 | 1 | 2 | 2 |
| Sum -'s | 1 | 0 | 1 | 2 |
| Net Score | 2 | 5 | 2 | 0 |
| Rank | 2 | 1 | 2 | 3 |
| Continue? | Combine | Combine | Combine | No |

| Selection Criteria | A 1 Floor | B 2 Floors |
|---|---|---|
| Learn Engineer Design Process | + | + |
| Scale Model | + | + |
| 3-D Computer Model | + | + |
| Meets Needs of Family of Four | - | + |
| Aesthetically Pleasing/ Atrractive Appearence | 0 | + |
| Sustainability | + | - |
| Sum +'s | 4 | 5 |
| Sum 0's | 1 | 0 |
| Sum -'s | 1 | 1 |
| Net Score | 3 | 4 |
| Rank | 2 | 1 |
| Continue? | Yes | No |

| Selection Criteria | A 1000-1500 sq ft | B 1500-2000 sq ft | C 2000-2500 sq ft |
|---|---|---|---|
| Learn Engineer Design Process | + | + | + |
| Scale Model | + | 0 | - |
| 3-D Computer Model | + | 0 | - |
| Meets Needs of Family of Four | - | 0 | + |
| Aesthetically Pleasing/ Atrractive Appearence | 0 | 0 | 0 |
| Sustainability | + | 0 | - |
| Sum +'s | 4 | 1 | 2 |
| Sum 0's | 1 | 5 | 1 |
| Sum -'s | 1 | 0 | 3 |
| Net Score | 3 | 1 | -1 |
| Rank | 2 | 1 | 0 |
| Continue? | Yes | No | No |

| Selection Criteria | A < 2 Bathrooms | B > 2 Bathrooms |
|---|---|---|
| Learn Engineer Design Process | + | + |
| Scale Model | + | - |
| 3-D Computer Model | + | - |
| Meets Needs of Family of Four | - | + |
| Aesthetically Pleasing/ Atrractive Appearence | - | + |
| Sustainability | + | - |
| Sum +'s | 4 | 3 |
| Sum 0's | 0 | 0 |
| Sum -'s | 2 | 3 |
| Net Score | 2 | 0 |
| Rank | 1 | 2 |
| Continue? | Yes | No |

| Selection Criteria | A<br>Wood | B<br>Stone |
|---|---|---|
| Learn Engineer Design Process | + | + |
| Scale Model | 0 | 0 |
| 3-D Computer Model | 0 | 0 |
| Meets Needs of Family of Four | + | + |
| Aesthetically Pleasing/ Atrractive Appearence | + | + |
| Sustainability | 0 | + |
| Sum +'s | 3 | 4 |
| Sum 0's | 3 | 2 |
| Sum -'s | 0 | 0 |
| Net Score | 3 | 4 |
| Rank | 2 | 1 |
| Continue? | No | Yes |

| | | Concepts | | | | | |
|---|---|---|---|---|---|---|---|
| | | A<br>Active Solar | | B<br>Passive Solar | | C<br>Wind | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| Learn Engineer Design Process | 10% | 3 | 0.3 | 3 | 0.3 | 3 | 0.3 |
| Scale Model | 5% | 3 | 0.15 | 4 | 0.2 | 3 | 0.15 |
| 3-D Computer Model | 5% | 3 | 0.15 | 3 | 0.15 | 2 | 0.1 |
| Meets Needs of Family of Four | 30% | 4 | 1.2 | 4 | 1.2 | 5 | 1.5 |
| Aesthetically Pleasing | 20% | 3 | 0.6 | 3 | 0.6 | 3 | 0.6 |
| Sustainability | 30% | 5 | 1.5 | 4 | 1.2 | 5 | 1.5 |
| | Total Score | 3.9 | | 3.65 | | 4.15 | |
| | Rank | 2 | | 3 | | 1 | |
| | Continue? | Develop | | Develop | | Develop | |

| | | Concepts | | | |
|---|---|---|---|---|---|
| | | A<br>1 Floor | | B<br>2 Floors | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score |
| Learn Engineer Design Process | 10% | 2 | 0.2 | 3 | 0.3 |
| Scale Model | 5% | 5 | 0.25 | 3 | 0.15 |
| 3-D Computer Model | 5% | 5 | 0.25 | 3 | 0.15 |
| Meets Needs of Family of Four | 30% | 2 | 0.6 | 4 | 1.2 |
| Aesthetically Pleasing | 20% | 2 | 0.4 | 4 | 0.8 |
| Sustainability | 30% | 5 | 1.5 | 3 | 0.9 |
| Total Score | | 3.2 | | 3.5 | |
| Rank | | 1 | | 2 | |
| Continue? | | Develop (Cheaper) | | No | |

| | | Concepts | | | | | |
|---|---|---|---|---|---|---|---|
| | | A<br>1000-1500 sq ft | | B<br>1500-2000 sq ft | | C<br>2000-2500 sq ft | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score |
| Learn Engineer Design Process | 10% | 2 | 0.2 | 3 | 0.3 | 4 | 0.4 |
| Scale Model | 5% | 5 | 0.25 | 4 | 0.2 | 3 | 0.15 |
| 3-D Computer Model | 5% | 5 | 0.25 | 4 | 0.2 | 3 | 0.15 |
| Meets Needs of Family of Four | 30% | 2 | 0.6 | 3 | 0.9 | 4 | 1.2 |
| Aesthetically Pleasing | 20% | 2 | 0.4 | 3 | 0.6 | 4 | 0.8 |
| Sustainability | 30% | 5 | 1.5 | 4 | 1.2 | 3 | 0.9 |
| Total Score | | 3.2 | | 3.4 | | 3.6 | |
| Rank | | 1 | | 2 | | 3 | |
| Continue? | | Develop (Cheaper) | | No | | No | |

| | | Concepts | | | |
|---|---|---|---|---|---|
| | | A < 2 Bathrooms | | B > 2 Bathrooms | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score |
| Learn Engineer Design Process | 10% | 3 | 0.3 | 4 | 0.4 |
| Scale Model | 5% | 2 | 0.1 | 3 | 0.15 |
| 3-D Computer Model | 5% | 2 | 0.1 | 3 | 0.15 |
| Meets Needs of Family of Four | 30% | 2 | 0.6 | 4 | 1.2 |
| Aesthetically Pleasing | 20% | 2 | 0.4 | 3 | 0.6 |
| Sustainability | 30% | 4 | 1.2 | 3 | 0.9 |
| | Total Score | 2.7 | | 3.4 | |
| | Rank | 1 | | 2 | |
| | Continue? | Develop (Cheaper) | | No | |

| | | Concepts | | | |
|---|---|---|---|---|---|
| | | A Wood | | B Stone | |
| Selection Criteria | Weight | Rating | Weighted Score | Rating | Weighted Score |
| Learn Engineer Design Process | 10% | 4 | 0.4 | 4 | 0.4 |
| Scale Model | 5% | 3 | 0.15 | 3 | 0.15 |
| 3-D Computer Model | 5% | 3 | 0.15 | 3 | 0.15 |
| Meets Needs of Family of Four | 30% | 4 | 1.2 | 4 | 1.2 |
| Aesthetically Pleasing | 20% | 4 | 0.8 | 4 | 0.8 |
| Sustainability | 30% | 3 | 0.9 | 4 | 1.2 |
| | Total Score | 3.6 | | 3.9 | |
| | Rank | 2 | | 1 | |
| | Continue? | No | | Develop | |

## Final Design

After all the research and brainstorming, our group was able to finalize a house that would fit the needs of the family and stay under budget. It will be a one story home located in Allentown, PA and contain 1080 square feet. Our home's renewable energy resources will be both active and passive solar and also wind power. The walls will be insulated with R-60, while the ceiling will be insulated with R-40. It will include two bedrooms with one being a master bedroom. Our windows will have Triple low-e to keep the heat in the house. Our appliances will all be energy star level for the best efficiency. The base cost of our home will end up being $124,863. With the average American home producing 11,000 and more kwh, our home will produce only about 6,000 kwh to meet the basic needs of the family. Our PV

output will mostly cover this energy needed and will cost $22,770 for the panels. The house will face 45° south and have four large windows to help with the passive solar heating. With the extra money left over from building, we were able to buy two turbines that will produce and extra 1967 kilowatt-hours and cost only $7,000. Shown below is our Zero Energy Home calculator and what it took to design our house to a finalized scale model. The next picture shows how much money we could be potentially saving based off the renewable energy sources. Annually we will be saving about $450 each year. This is not including the money return from the wind turbines. Our annual pay back will be over $500 once the investments on the house are made back. The final part is all of the pictures of the house in sketch, CAD, and model formats.

ZEH Calculator:

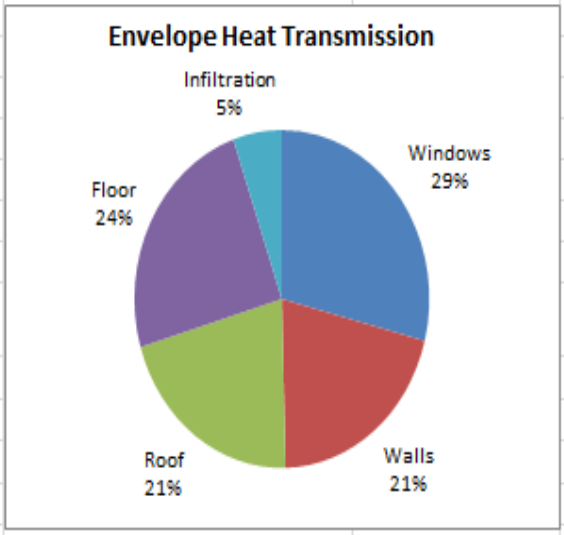
## Penn State Center for Sustainability

| General Info | |
|---|---|
| Location | Allentown |
| Electricity cost ($/kwh) | 0.077 |
| House type | 1 story |
| Conditioned floor area (sq.ft.) | 1080 |
| Number of bedrooms | 2 |
| **Envelope Details** | |
| Wall construction | Double 2x4 with 10" foam |
| Ceiling Insulation | R40 |
| Window type | Triple low-e |
| Upper floor ceiling area (sq.ft.) | 1080 |
| North wall area (gross) (sq.ft.) | 270 |
| East wall area (sq.ft.) | 400 |
| South wall area (sq.ft.) | 270 |
| West wall area (sq.ft.) | 400 |
| North window area (sq.ft.) | 24 |
| East window area (sq.ft.) | 36 |
| South window area (sq.ft.) | 131 |
| West window area (sq.ft.) | 48 |
| Air tightness | Tight with heat recovery |
| **Appliances** | |
| Refrigerator | Energy Star |
| Clothes Washer | Energy Star |
| Dishwasher | Energy Star |
| Small Appliance Input | |
| **Extras** | |
| Garage | a. none |
| Hot Tub | a. None |
| Pool | a. None |

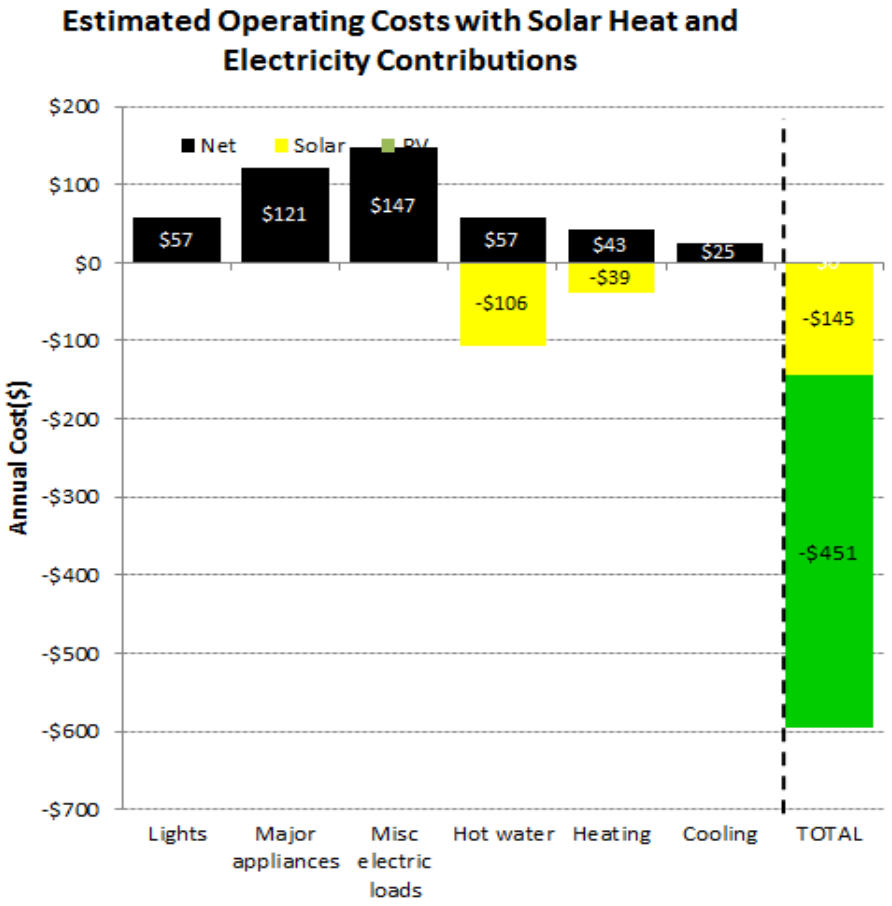
## Zero Energy Home Calculator

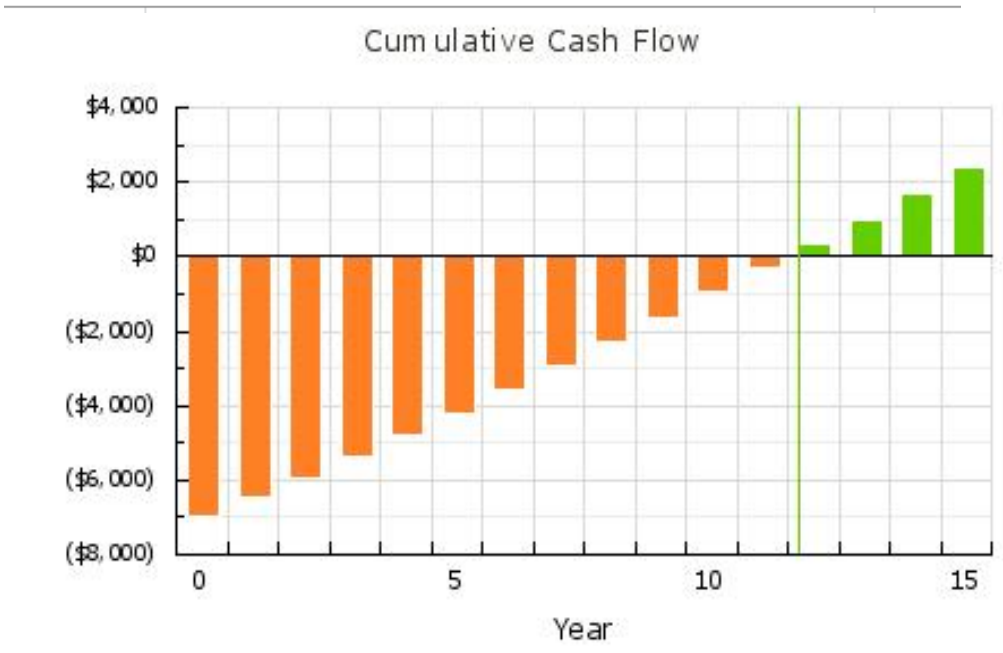
| Heating & Cooling | |
|---|---|
| Type of heating & cooling system | Electric geothermal heat pump |
| **Solar Technologies** | |
| Size of PV system (kw) | 4.55 |
| Solar water heater | Yes |
| **Behavior** | |
| Water conservation | A lot |
| Uses clothesline | A lot |
| Thermostat setback | Some |
| Heat thermostat setting (F) | 72 |
| Cool thermostat setting (F) | 72 |

**Results**




| | | |
|---|---|---|
| **Base House Cost** | **$** | **124,863** |
| **PV Cost** | **$** | **22,770** |
| **Upgrade Costs** | **$** | **19,321** |
| **Total House Cost** | **$** | **166,954** |

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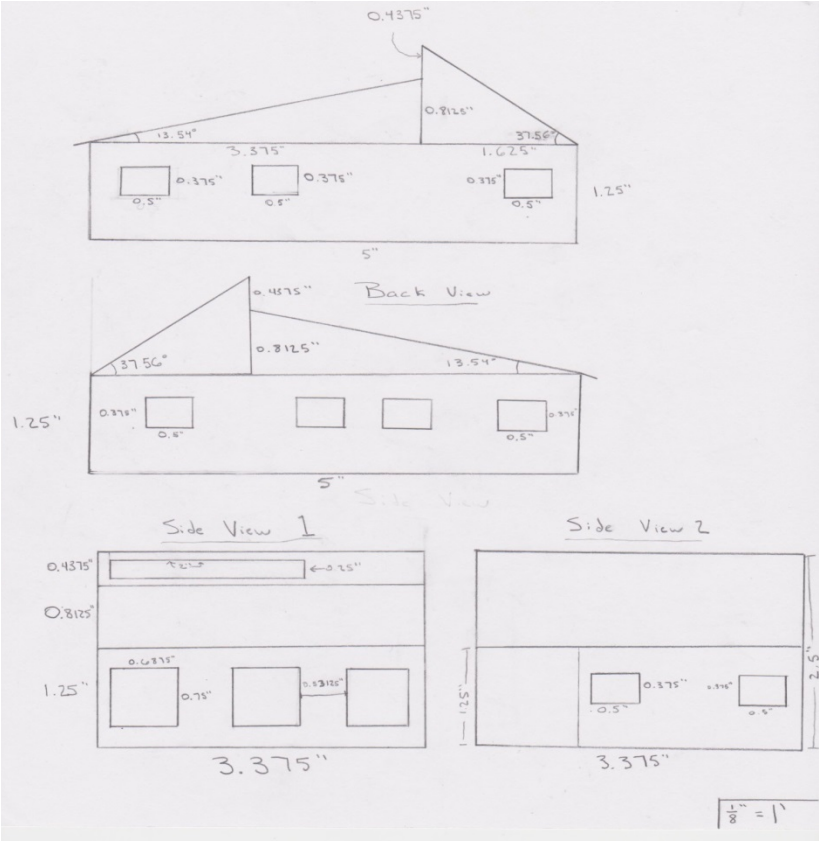
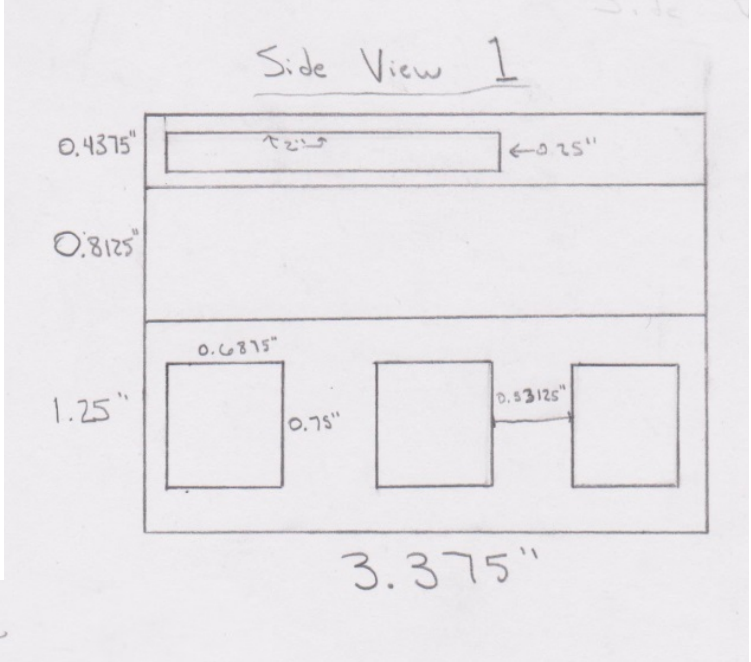
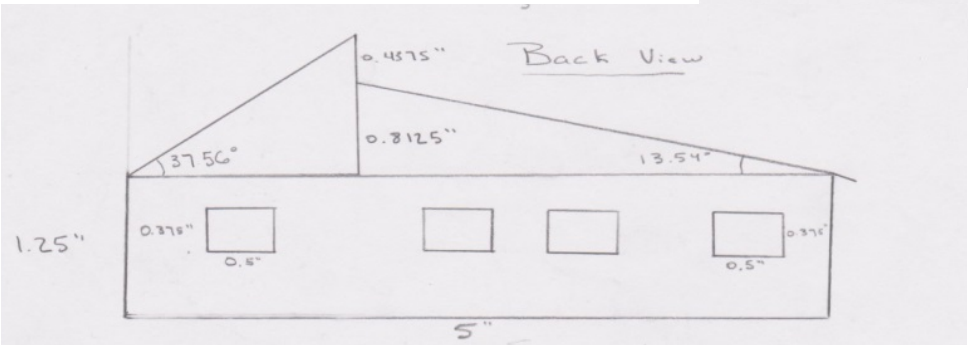
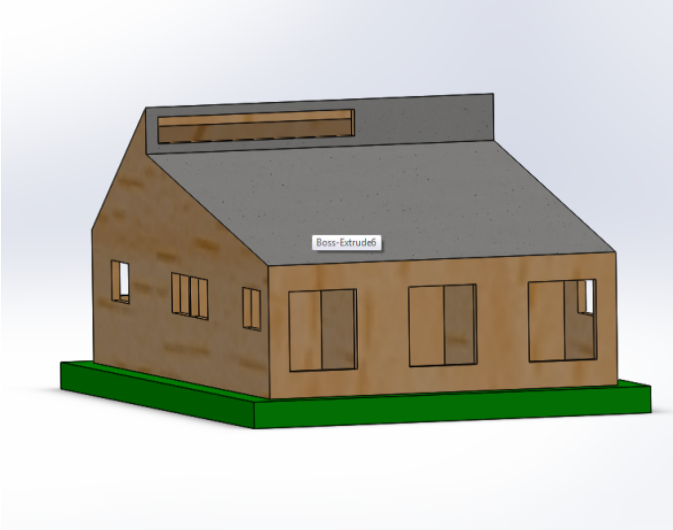
Sketches:

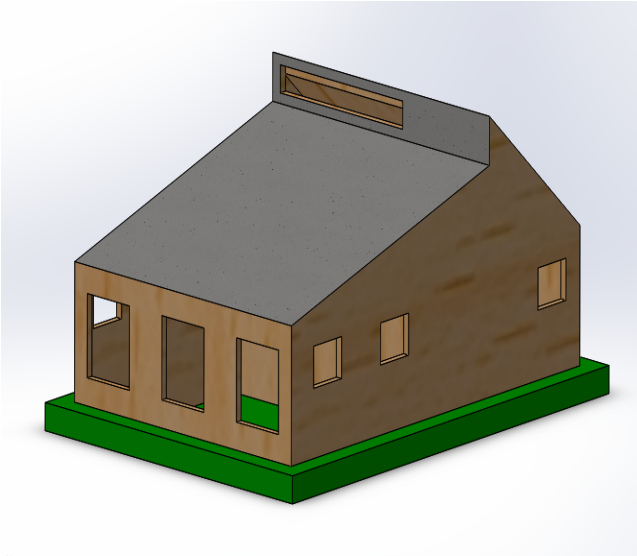

0.4375"
0.8125"
13.54°
37.56°
3.375"
1.625"
0.375"
0.375"
0.375"
0.5"
0.5"
0.5"
1.25"
5"
Back View
0.4375"
0.8125"
37.56°
13.54°
1.25"
0.375"
0.5"
0.5"
0.375"
5"
Side View 1
Side View 2
0.4375"
0.25"
0.8125"
0.6875"
1.25"
0.75"
0.53125"
3.375"
1.25"
0.375"
0.375"
0.5"
0.5"
2.5"
3.375"
1/8" = 1'

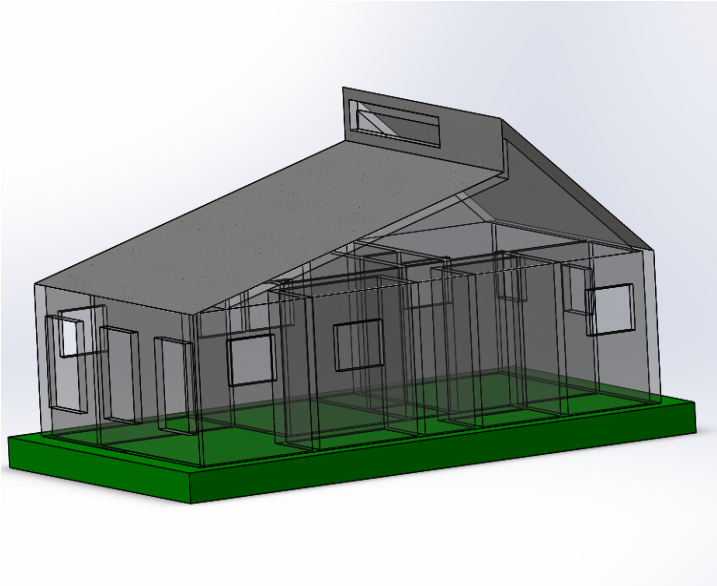

Side View 1
0.4375"
0.25"
0.8125"
0.6875"
1.25"
0.75"
0.53125"
3.375"

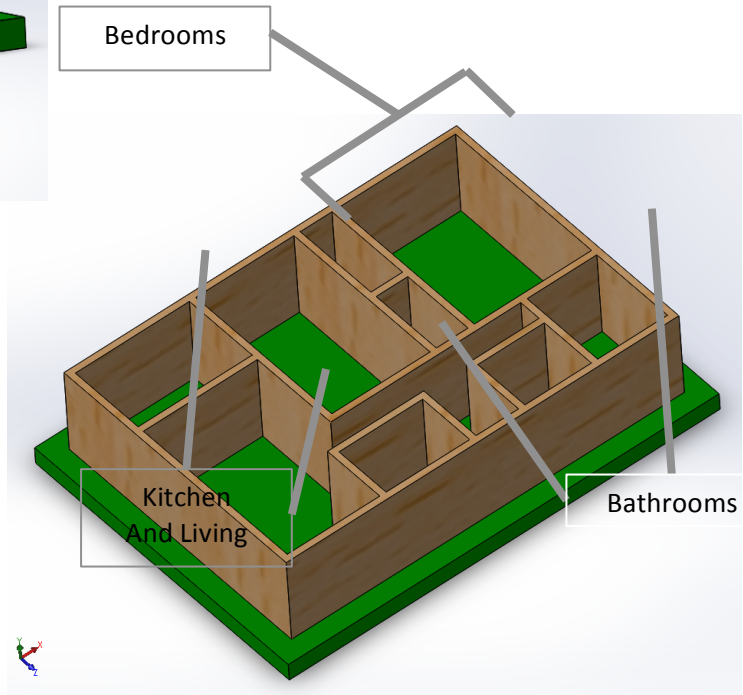

0.4375"
Back View
0.8125"
37.56°
13.54°
1.25"
0.375"
0.5"
0.5"
0.375"
5"

Solidworks:

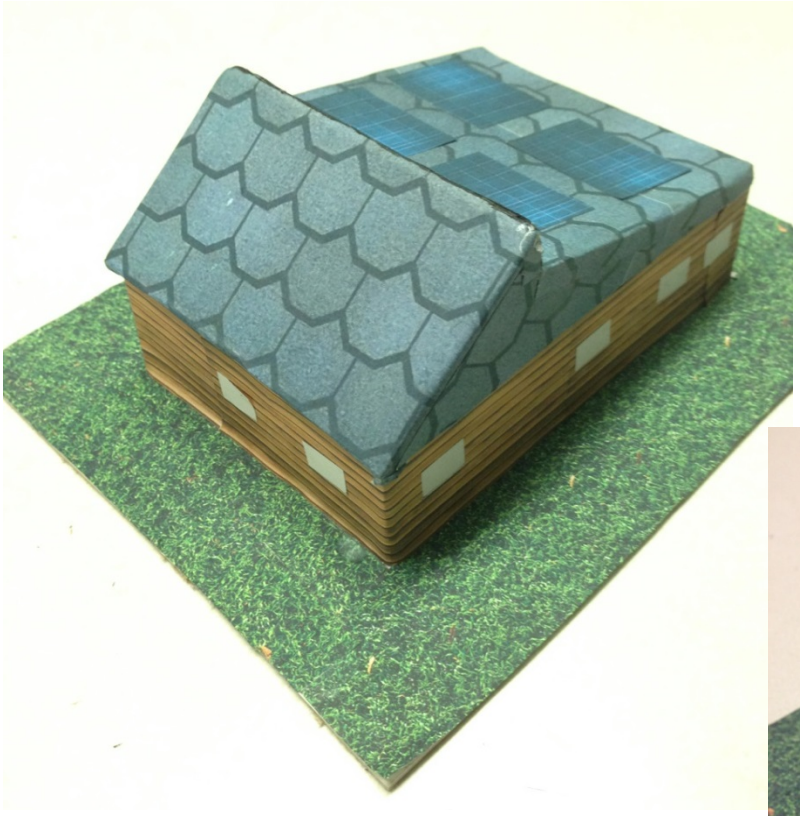


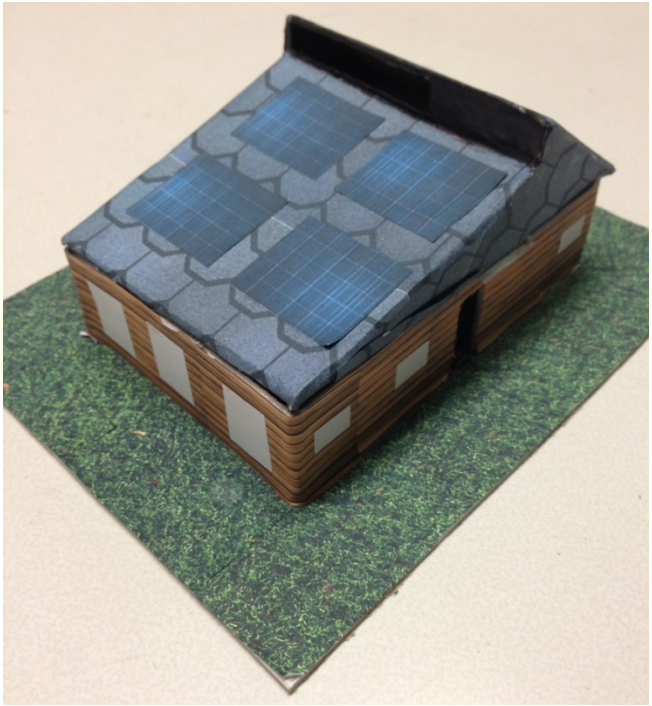







Scale Model:





# Conclusions

We learned a lot about the engineering design process during this project. We were able to create a house that we were all proud of in the end. After long brainstorming, and many decisions, we produced a suitable house for a family. We each put our own taste into the house and made it to the customer needs. The house is capable of producing its own energy and is suitable for people who are new to real estate. There is a great opportunity to grow a family in this home and improve on the quality of the environment at the same time. The future is going to be based off energy that is renewable. This house definitely takes on the role as the house of the future.

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